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Author(s):	Weller, Michael Welch, D. R.
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Los Alamos NATIONAL LABORATORY

ASD Scorpius	**Technical Note**

Modeling Fast-Valve in Chicago to Check for RF Oscillations and Beam Degradation (LA-UR-22-21023)

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APPROVALS

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Scorpius Technical Note

Modeling Fast-Valve in Chicago to Check for RF Oscillations and Beam Degradation

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Section I: General Overview and Purpose of Work

A Fast-Valve is currently being planned for Region 1 in the Down Stream Transport (DST) in Scorpius[1]. There are concerns about a possible effect this particular Fast-Valve will have on the beam, such as producing RF oscillations. The Fast-Valve in question was made by VAT[2] and is Series 75.0. Figure 1 shows a schematic of the Fast-Valve in the beam pipe of Region 1 of the DST and also shows a 3D rendering. To answer the effects of beam degradation, a 3D Chicago model was implemented and several simulations were performed. This Technical Note documents the results of the simulations as well as ensuring additional simulations can be performed in the future with relative ease.

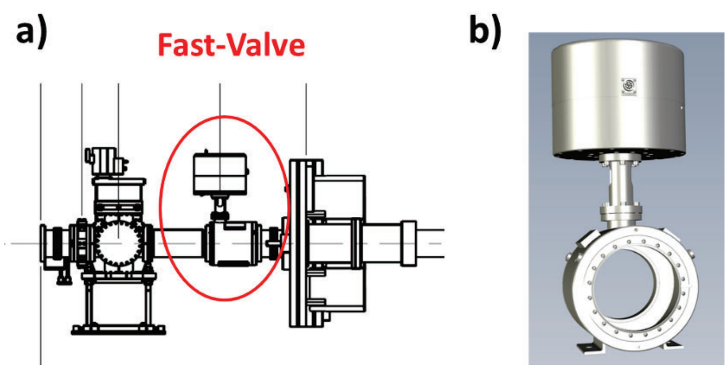

Figure 1: *a) A schematic of the Fast-Valve in the DST and b) a 3D rendering of the Fast-Valve*

Section II: Simulation Setup and Initial Conditions

To capture the full effects of the beam degradation, a 3D Chicago simulation was performed. To drastically cut down on computational time, only about 25 cm beam transport before and after the Fast-Valve is included. The beam parameters of the injected beam are as follows: 22.5 MeV, 1.47 kA, 1 cm RMS radius, no B_z magnetic field (in between magnets, no field present), 0.125-π-rad-cm emittance, and a 0.5 mm Y-offset. The 3D Cartesian Grid was set up with a 1.0 mm Transverse resolution, a 1.7 mm Axial resolution, and a 2.2 ps temporal resolution. The full Chicago deck has been cut and pasted in Appendix I for convenience. Different rise-times of the beam were used, including a 15 ns, 1 ns, 0.333 ns, and an LSP calculated rise (generated from a pulse shape provided by a CASTLE simulation from Ray Allen of NRL).

Figure 2 shows how this setup looks like as a cross section of the output. A Solid Works .stp file of the Fast-Valve was provided directly from VAT and was used to convert to a 3D model in Chicago.

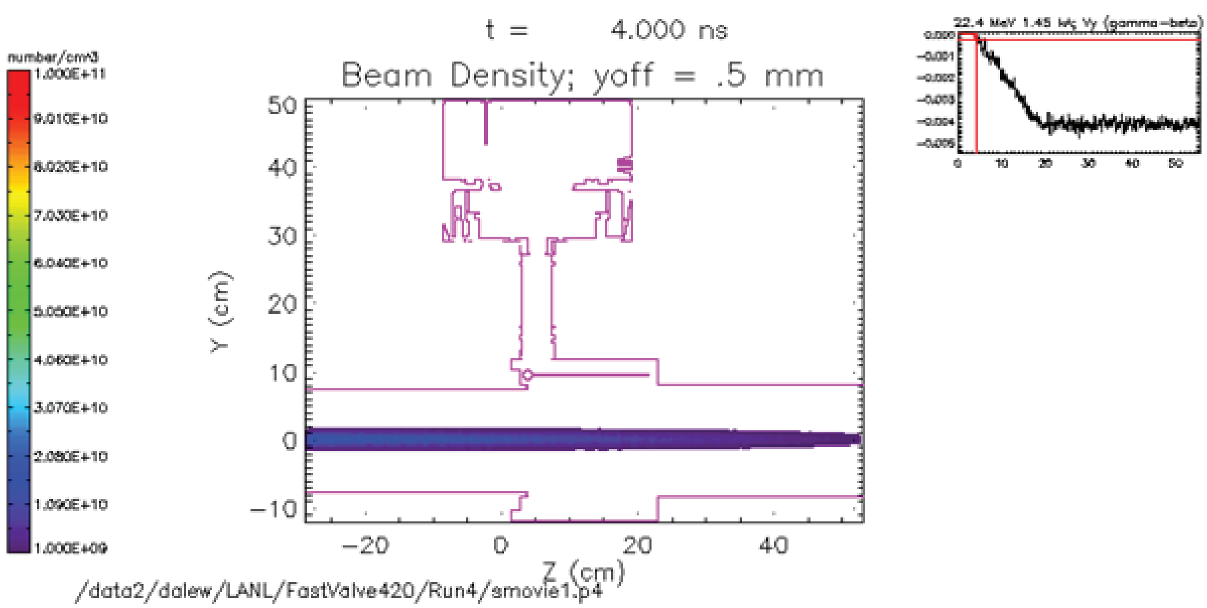

Figure 2: *Example of a cross section of the 3D Chicago model.*

Section III: Simulation Results

Results of the fully electromagnetic 3D simulations are shown in this section. To begin, Figure 3 shows the evolution of the electron number density as a function of for time slices. These initial simulations were performed with a time-rise of 15 ns. Other time-rise simulations are shown later.

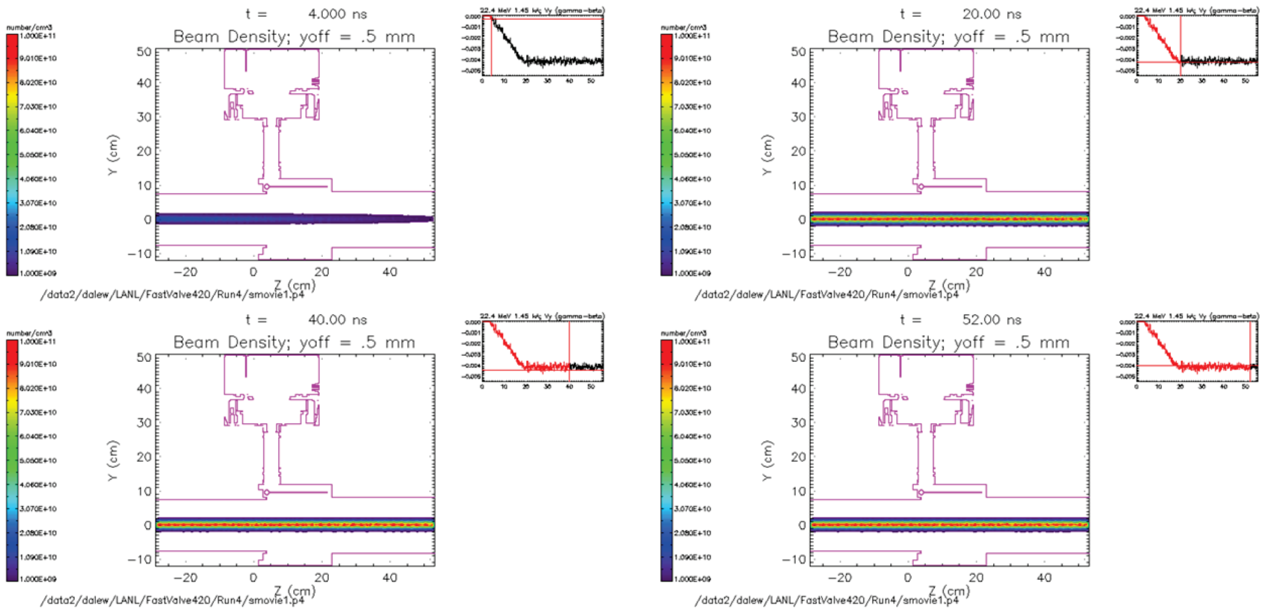

Figure 3: *Evolution of electron number density as a function of four different times.*

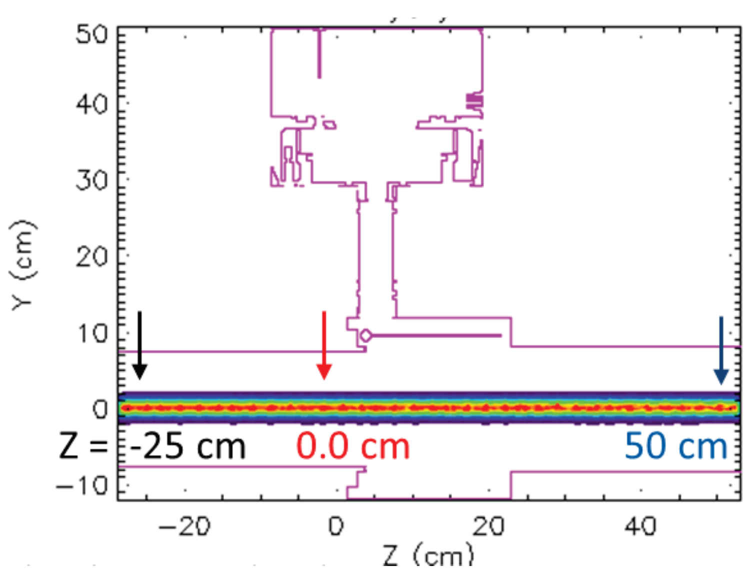

Figure 4: *Locations of where Beam Moments were captured.*

Figure 4 shows were different beam moments were captured for the 15-ns rise-time case. The moments were captured at -25 cm, 0.0 cm, and 50 cm. The results of the emittance, X impulse, and Y impulse (in terms of γβ) are shown in Figure 5. The results indicate no emittance degradation, but beam sustains a $\gamma\beta_y = 0.004$ impulse, or a 9×10^{-5} c velocity. This Y impulse was not due to the offset, as no offset simulation had the same impulse. This will add to cork screw motion.

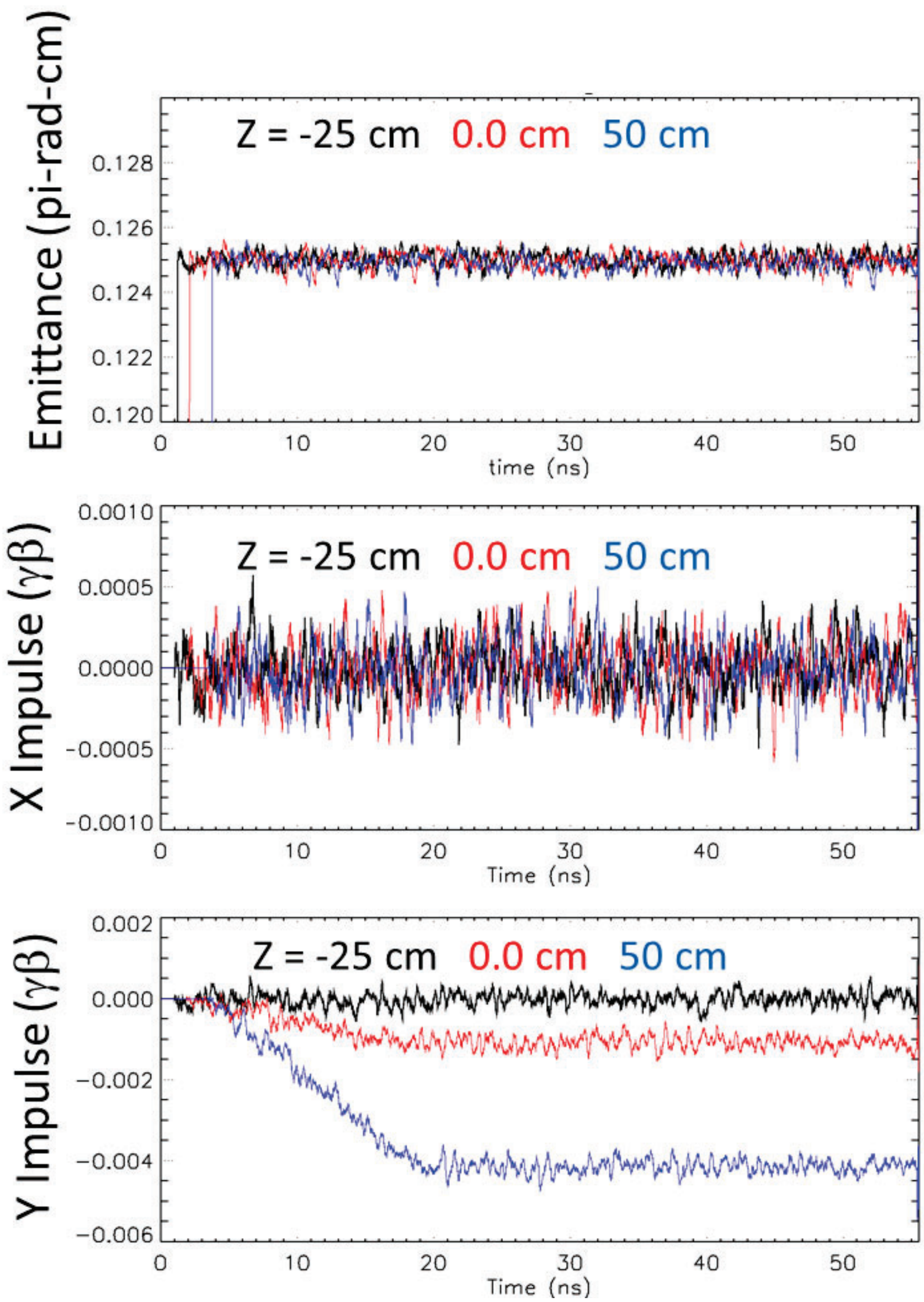

Figure 5: *Results of emittance (top), X impulse (middle) and Y impulse (bottom).*

The electric field map is shown in Figure 6. The important takeaway here is that the electric field falls off "dramatically" in the Fast-Valve, which indicates that the mode coupling is weak.

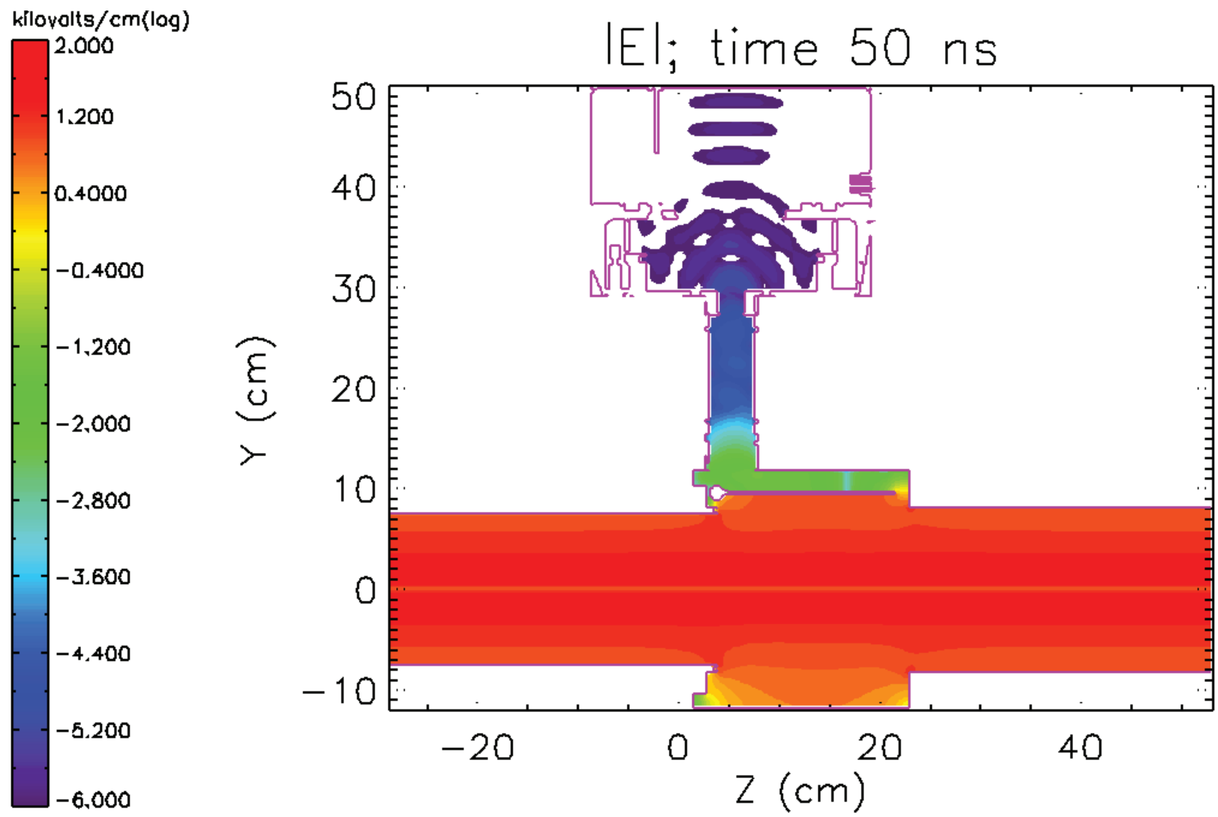

Figure 6: *Results of the Electric Field.*

Figure 7 shows additional results for the electric fields and beam motion. The beam impulse is of the order of 5% of the total intrinsic V_y motion, which will feed into cork screw initially. The beam impulse and axial field asymmetry scale with the beam current. The 0.004 impulse (from Figure 5) compares with a ± 0.0004 ambient beam. This additional motion in turn could degrade beam emittance by 5%. As far as RF oscillations are concerned, Figure 7 shows that at z = 10 cm, there is a 15% deviation in longitudinal E field from symmetric with a 0.02 kV/cm peak at 1 GHz.

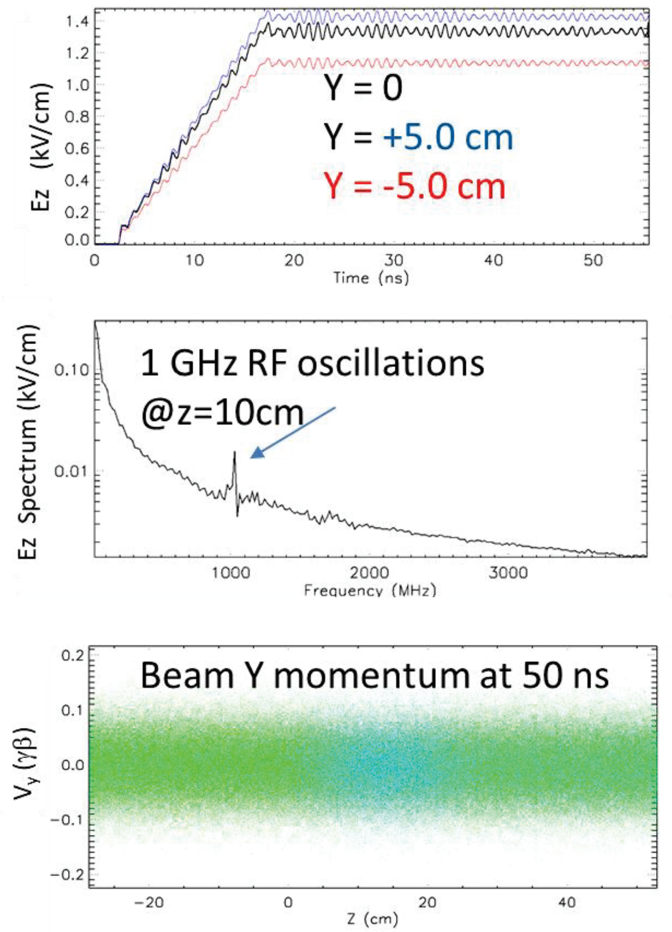

Figure 7: *Results of the Ez (top), Ez Spectrum (middle), and Vy (bottom).*

Figure 8 shows input waveforms of different time-rise and compares with the 15 ns results shown so far. Note that the LSP calculated waveform was produced by using a CASTLE simulation from Ray Allen of NRL and taking the result of the beam scraped waveform at the end of the Injector of a 2D LSP simulation.

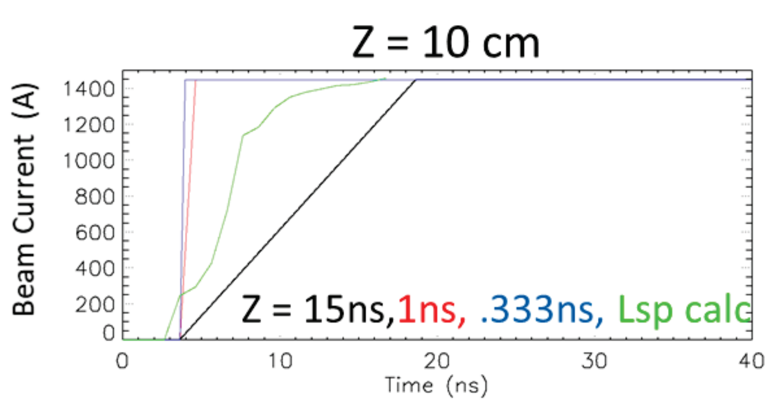

Figure 8: *Results of the Ez (top), Ez Spectrum (middle), and Vy (bottom).*

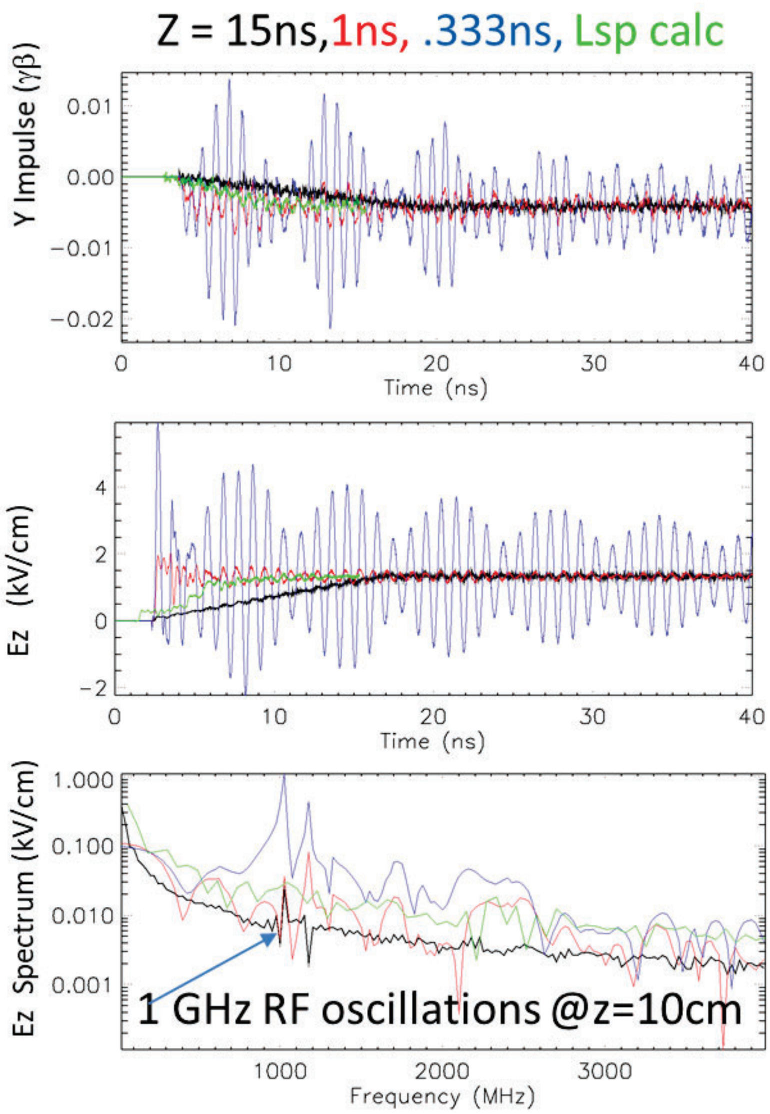

Figure 9: *Different rise-time simulation results of Y Impulse (top), Ez (middle) and Ez Spectrum (bottom).*

The results of the different rise-time simulations are shown in Figure 9. The major takeaways here is that the 1 GHz component grows inversely with the rise-time. Low frequency beam impulse scales with beam current. The high frequency imprint is five times larger at 0.333 ns rise-time. The emittance can be degraded between 5-20%. Figures 10 and shows the results of the LSP calculated current pulse shape. The results indicate a 0.0012 γβ impulse and a 0.01 cm RMS offset. There is also a well-defined peak at 1.1-1.3 GHz at 0.00025 amplitude. Overall for this pulse-shape, which is the best pulse shape we currently have to represent Scorpius, the Y offset and impulse should not significantly degrade the beam.

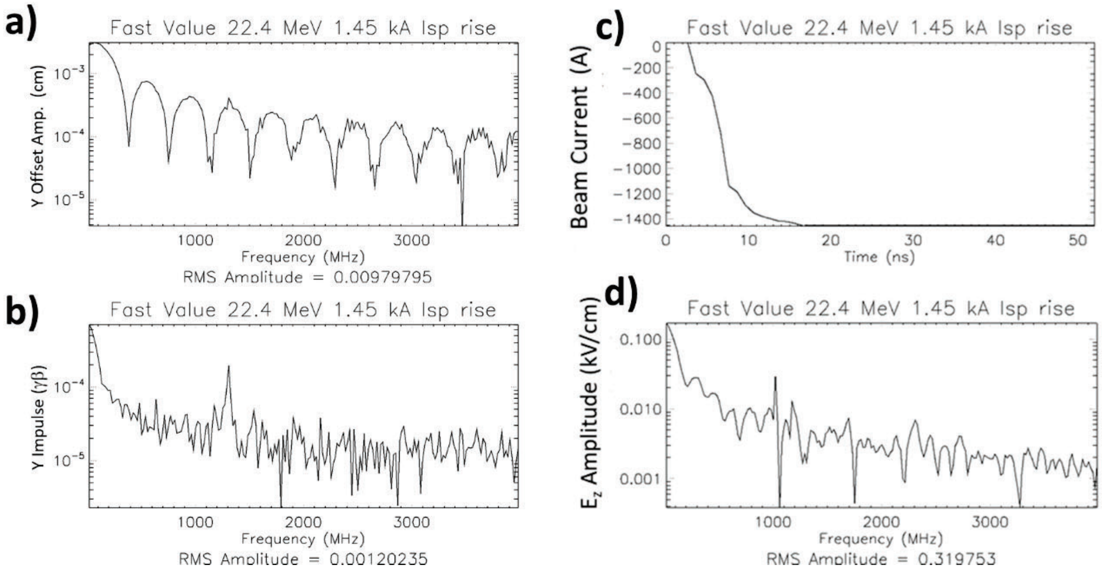

Figure 10: *Results of the LPS generated current pulse shape. a) is the Y offset, b) is the Y impulse, c) is the beam current, and d) is the Ez amplitude.*

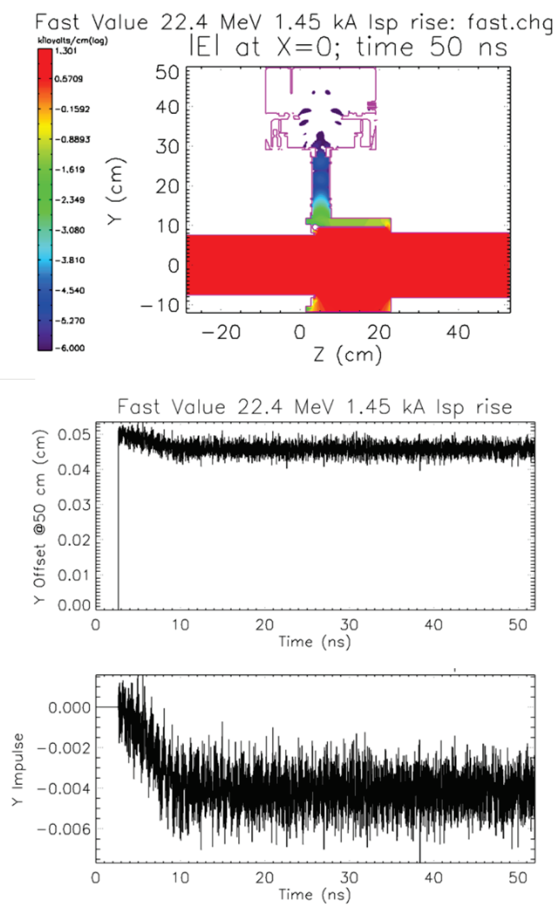

Figure 11: *Results of the LPS generated current pulse shape of the E field (top), the Y offset (middle) and the Y impulse (bottom).*

Section IV: Conclusions

3D Chicago simulations of the impact of the Fast-Valve has on an electron beam with Scorpius parameters has been accomplished. The Fast-Valve was accurately converted to Chicago from a .stp file provided from VAT. Initial results from a 15 ns rise time pulse and the more realistic LSP generated current pulse exhibits little degradation except an impulse in the Y direction of order 5% of the beam $\gamma\beta_y$. A weak coupling of 1 GHz frequency with the Fast-Valve was calculated and was shown to grow inversely with the rise-tme. For example, the LSP generated current pulse produced a several times larger GHz amplitude than the 15 ns rise-time, but was found to be much smaller still than the intrinsic motion of the incoming beam. In order for the Fast-Valve to significantly affect the beam transverse motion, a rise-time of < 1 ns is required. Additional simulations may be needed later to account for other effects.

Section V: References

[1]M. Crawford and J. Barraza, "Scorpius: The development of a new multi-pulse radiographic system," *IEEE 21st International Conference on Pulsed Power*, 2017.

[2]https://www.vatvalve.com/series/ultra-high-vacuum-fast-closing-valve-flap-valve-version

Appendix: Chicago Deck

Below is a cut and paste deck of the Chicago file used. Currently, Michael Weller has the documentation for the Chicago Deck for the 3D Fast-Valve simulation and other pertinent documents.

```
[Title]
simulation_title "Fast Value 22.4 MeV 1.45 kA lsp rise"
;
[Control]
;
;Time-advance
; courant_multiplier 0.9
;  number_of_steps 100
 time_limit_ns 100.0
 time_step_cm 0.0655 ; 0.0867
 wall_time 95.
;Restarts
 dump_restart_flag ON
 rename_restart_flag ON
 restart_interval_ns 250
;Parallel Processing
 balance_interval_ns 200
 initial_balance_flag OFF
 region_balance_flag OFF
```

```
 override_balance_flag OFF
 load_timing_interval 20
;Field Solution and Modification
 time_bias_coefficient 0.5 ; 0.25
 time_bias_iterations 4
 electric_force_filtering_parameter 0.9
 magnetic_force_filtering_parameter 0.9
 field_advance_flag on
;(Diagnostic Output) Flags
 dump_time_zero_flag OFF
;(Diagnostic Output) Dump Intervals
 dump_interval_ns 10.0
 field_dump_steps 1 end
 field_movie_interval_ns 4.0
 field_movie_components EX EZ BY BZ VX VY VZ
 field_movie_coordinate X 0.0
 scalar_movie_interval_ns 4.0
 scalar_movie_components number_densities
 scalar_movie_coordinate X 0.0
 probe_interval 4
;(Diagnostic Output) Formats
 probe_output_digits 14
;Numerical Checks and Reports
 print_convergence_flag OFF
 dump_timing_flag on
 report_timing_flag on
;
[Grid]
;
grid1
xmin        -13.9
xmax         13.9
x-cells     278
;
ymin        -11.9
ymax         49.9
y-cells     618
;
zmin        -28.6 ; high res needed from 23.0 to -8.7
zmax         52.9
z-cells     470
;z-intervals
; dz-start     0.4
; length       10.4 for 26
; length       9.5 for 38 ; transition
; length       31.7 for 317
; length       9.5 for 38 ; transition
; length       20.4 for 51
```

```
;
[Regions]
region1 ; region 1
grid 1
xmin -13.9
xmax  13.9
ymin -11.9
ymax  49.9
zmin -28.6
zmax  52.9
number_of_domains 120
split_direction YSPLIT
number_of_cells AUTO
;
[Objects]
;
object1 SOLID
conductor on medium 0 potential 0
;
object2 FUNCTION 1
coordinates default
conductor off medium 0 potential 0
;
object3 CYLINDER ; input tube
conductor off medium 0 potential 0
base 0 0 1.4
polar_angle Z 180
azimuthal_angle X 0
height 40
radius 7.5
start_angle 0 sweep_angle 360
;
object4 CYLINDER ; output tube
conductor off medium 0 potential 0
base 0 0 22.9
polar_angle Z 0
azimuthal_angle X 0
height 40
radius 8.2
start_angle 0 sweep_angle 360
;
[Boundaries]
;
outlet
from -13.5 -13.5 -28.6
to  13.5 13.5 -28.6
drive_model NONE
;
```

```
outlet
from -13.5 -13.5 52.9
to  13.5 13.5  52.9
drive_model NONE
;

[Particle Species]
;
species1 ; kinetic electrons, cathode
charge -1
mass 1.0
migrant_species_flag off
implicit_species_flag off
particle_motion_flag on
particle_forces_option AVERAGED ; PRIMARY
transverse_weighting_flag on
particle_kinematics_option STANDARD
;surface_reflection_type 2
scattering_flag off
binary_collision_flag off ; on
selection_ratio 0.2
;
[Particle Creation]
;
injection
from -3.0 -3.0  -28.6
to    3.0  3.0  -28.6
normal Z
interval 1
species 1
discrete_numbers 2 2 1
temporal_function 4
spatial_function 3
drift_momentum 0.0 0.0 44.8244 ; 11.5193
reference_point 0 0.05 0
spatial_flags 1 1 0
rotation on
omega 0.0 ; 0.007; 0.0192
thermal_energy 1000.0
;
[External Fields]
;
external 1
type CONSTANT
field B Z 0.0 ; 760.0
;
[Functions]
;
```

```
function1
type script
"def step_valve(x,y,z):
   # ;Step file is opened in mathlib.py
   # ;evaluate_point is defined in mathlib.py
   (x1,y1) = (9.9243,9.0774)
   (x2,y2) = (6.8157,11.5947)
   m = (y2-y1)/(x2-x1)
   th1 = atan2(y1,x1)
   th2 = atan2(y2,x2)

   r = sqrt(x**2+y**2)
   th = atan2(y,x)

   reg1test = (22.9>=z) & (z>=1.4) & ((x**2+y**2)<=11.8**2)
   reg2test = (29.1<=y) & (y<=49.8) & ((x**2+(z-5.2)**2)<=13.82**2)
   reg3test = (0<=y) & (y<=29.1) & ((x**2+(z-5.2)**2)<=2.55**2)
   reg4test = (18.75>=z) & (z>=7.75) & (r<=(y1-m*x1)/(sin(th)-m*cos(th))) & (th1<=th) & (th<=th2)
   reg5test = (18.75>=z) & (z>=7.75) & (r<=(y1-m*x1)/(sin(th)+m*cos(th))) & ((pi-th1)>=th) & (th>=(pi-
th2))

   if reg1test or reg2test or reg3test or reg4test or reg5test:
      return(evaluate_point(valve,x,y,z)^1) #byte math to invert logic
   else:
      return(0)"
;
function2
type script
"def flat_top(t):
   mag = 461.0
   t_rise = 15.0
   t_flat = 60.0
   t_strt = 1.0

   t_end = t_strt + t_flat + 2*t_rise

   val = 0.0

   if t > t_strt and t < t_end:
      if t > t_strt + t_rise and t < t_end - t_rise:
         val = mag
      else:
         t_mid = t_strt + t_rise + 0.5*t_flat
         t_dif = abs(t-t_mid) - 0.5*t_flat
         val = mag*(1.0-t_dif/t_rise)
   return(val)"
;
function3
```

```
type script
"def gaussian(x,y):
   mag = 0.9477/3.14159
   xb = 1.0
   r2 = x*x+y*y
   val = mag*exp(-1.*r2/(xb*xb))
   return(val)"
;
function4
type 0
data_pairs
0. 0.0
1. 260
2.0 312.
3.0 450.
4.0 760.
5.0 1201.
6.0 1251.
7.0 1363.
8.0 1427.
9.0 1456.
10. 1475.
11. 1495.
12. 1500.
13. 1515.
14. 1536.
15. 1530
50.0 1530.
55.0 1475
60.0 1201
65.0 0.0
100 0.0
end
[Probes]
probe1 performance cpu_time
probe2 performance DT_VARIABLE
probe 3 energy net_energy
probe 4 energy particle_energy
probe 5  performance maximum_residue
probe 6  performance total_residue
probe 7  energy total_particle_gain
probe 8  energy field_flux
probe 9  convergence iterations
probe 10  performance CPU_TIME
;
probe 11 particle radrms species 1
direction Z at 0.0 0.0 -25
r-window 7.375
```

```
probe 12 particle radrms species 1
direction Z at 0.0 0.0 0
r-window 7.375
probe 13 particle radrms species 1
direction Z at 0.0 0.0 25
r-window 7.375
probe 14 particle radrms species 1
direction Z at 0.0 0.0 50
r-window 7.375
;
probe 15 particle emittance species 1
direction Z at 0.0 0.0 -25
r-window 7.375
probe 16 particle emittance species 1
direction Z at 0.0 0.0 0
r-window 7.375
probe 17 particle emittance species 1
direction Z at 0.0 0 25.
r-window 7.375
probe 18 particle emittance species 1
direction Z at 0.0 0.0 50
r-window 7.375
probe 19 particle gamma species 1
direction Z at 0.0 0.0 -25
r-window 7.375
probe 20 particle gamma species 1
direction Z at 0.0 0.0 0
r-window 7.375
probe 21 particle gamma species 1
direction Z at 0.0 0 25.
r-window 7.375
probe 22 particle gamma species 1
direction Z at 0.0 0.0 50
r-window 7.375
probe 23 particle dqdt species 1
direction Z at 0.0 0.0 -25
r-window 7.375
probe 24 particle dqdt species 1
direction Z at 0.0 0.0 0
r-window 7.375
probe 25 particle dqdt species 1
direction Z at 0.0 0 25.
r-window 7.375
probe 26 particle dqdt species 1
direction Z at 0.0 0.0 50
r-window 7.375
probe27
label "xbar -25"
```

```
particle xbar species 1 direction Z
at 0 0 -25.0
;
probe28
label "ybar -25"
particle ybar species 1 direction Z
at 0 0 -25.0
;
probe29
label "xbar 0"
particle xbar species 1 direction Z
at 0 0 0.0
;
probe30
label "ybar 0"
particle ybar species 1 direction Z
at 0 0 0.0
;
probe31
label "xbar 25"
particle xbar species 1 direction Z
at 0 0 25.0
;
probe32
label "ybar 25"
particle ybar species 1 direction Z
at 0 0 25.0
;
probe33
label "xbar 50"
particle xbar species 1 direction Z
at 0 0 50.0
;
probe34
label "ybar 50"
particle ybar species 1 direction Z
at 0 0 50.0
;
probe35
label "vxbar -25"
particle vxbar species 1 direction Z
at 0 0 -25.0
;
probe36
label "vybar -25"
particle vybar species 1 direction Z
at 0 0 -25.0
;
```

```
probe37
label "vxbar 0"
particle vxbar species 1 direction Z
at 0 0 0.0
;
probe38
label "vybar 0"
particle vybar species 1 direction Z
at 0 0 0.0
;
probe39
label "vxbar 50"
particle vxbar species 1 direction Z
at 0 0 50.0
;
probe40
label "vybar 50"
particle vybar species 1 direction Z
at 0 0 50.0
;
probe41
label "Ey 10"
field ENODE Y
at 0 0 10.0
;
probe42
label "Ex 10"
field ENODE X
at 0 0 10.0
;
probe43
label "Ez 10"
field ENODE Z
at 0 0 10.0
;
probe44
label "Ey 10"
field ENODE Y
at 0 5 10.0
;
probe45
label "Ex 10"
field ENODE X
at 0 5 10.0
;
probe46
label "Ez 10"
field ENODE Z
```

```
at 0 5 10.0
;
probe47
label "Ey 10"
field ENODE Y
at 0 -5 10.0
;
probe48
label "Ex 10"
field ENODE X
at 0 -5 10.0
;
probe49
label "Ez 10"
field ENODE Z
at 0 -5 10.0
;
probe50
label "Ey 10"
field ENODE Y
at 5 0 10.0
;
probe51
label "Ex 10"
field ENODE X
at 5 0 10.0
;
probe52
label "Ez 10"
field ENODE Z
at 5 0 10.0
;
```